

2005

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C. H. Luce

D. G. Tarboton

E. Istanbulluoglu

Robert T. Pack
Utah State University

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Recommended Citation

Luce, C.H., Tarboton, D.G., Istanbulluoglu, E. and Pack, R.T. 2005. Reply to Comment by Johathan J. Rhodes on “modeling and interactions between forest vegetation, disturbances, and sediment yields”. *Journal of Geophysical Research*, v.110, n.F01013, doi:10.1029/2004JF000279.

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Reply to comment by Jonathan J. Rhodes on “Modeling of the interactions between forest vegetation, disturbances, and sediment yields”

Charles H. Luce,¹ David G. Tarboton,² Erkan Istanbuluoglu,³ and Robert T. Pack²

Received 22 December 2004; accepted 31 December 2004; published 22 February 2005.

Citation: Luce, C. H., D. G. Tarboton, E. Istanbuluoglu, and R. T. Pack (2005), Reply to comment by Jonathan J. Rhodes on “Modeling of the interactions between forest vegetation, disturbances, and sediment yields,” *J. Geophys. Res.*, *110*, F01013, doi:10.1029/2004JF000279.

1. Introduction

[1] *Rhodes* [2005] brings up some excellent points in his comments on the work of *Istanbuluoglu et al.* [2004]. We appreciate the opportunity to respond because it is likely that other readers will also wonder how they can apply the relatively simple analysis to important policy questions. Models necessarily reduce the complexity of the problem to make it tractable and synthesize some diverse sources of information. It may be helpful at times for readers to understand the high dimension of the complexity sacrificed in order to obtain the synthesis and the reasons for reducing the complexity in a particular manner. *Rhodes* [2005] comments on three things: (1) the omission of roads and landings from the analysis; (2) the implicit assumption that fire does not occur with harvesting; and (3) the overestimation of water repellency. We will respond to each of these, clarifying and elaborating on the basis for our modeling choices.

2. Roads and Landings

[2] The primary reason for not including forest roads and landings from the analysis is philosophical: keeping the analysis simple enough that there are not a lot of additional assumptions that could obfuscate or condition the results. Even with the very simple analysis done, some thought must be used in applying the results.

[3] We agree that the exclusion of roads from the simulation could potentially bias the results; however, the bias introduced should be relatively small with respect to surface erosion. In unpublished work applying the results of *Luce and Black* [1999, 2001] to a road system in the Oregon Coast Range for an assessment related to land management decisions, the estimated annual yield from surface erosion

was about 1/10th of the annualized denudation rate for the Coast Range estimated by *Reneau and Dietrich* [1991]. Further evidence can be found by applying a little background on basins used by *Kirchner et al.* [2001]. He showed that measurements of sediment yield from small watersheds in the Idaho Batholith (notably Silver Creek and Horse Creek) taken over a period of about 30 years were about 1/10th of the long-term sediment yield estimated from cosmogenic nuclide concentrations. Some among these small watersheds had roads constructed in them to measure the effect of road building on basin sediment yields, and the total surface sediment production with roads present was still not on a par with the effects of long-term disturbance histories related to fire and climate. Upon examination of the potential sediment yields on an event basis following fires within batholith basins [e.g., *Istanbuluoglu et al.*, 2003; *Meyer and Pierce*, 2003], one can see that the reason for this result is the enormous sediment yields associated with individual fire events. Note that these arguments apply to steep landscapes where mass wasting occurs. Roads may be a more substantial component of the long-term sediment yield in low-relief landscapes.

[4] There are notable examples across the western United States where roads have dramatically increased sediment yields from small basins through mass wasting processes [*Wemple et al.*, 2001]. Estimating the relative contribution of mass wasting to the sediment yield from roads is difficult. A key difficulty is assessing the likelihood of failure from a road, which is strongly dependent on site characteristics and drainage [e.g., *Montgomery*, 1994; *Wemple et al.*, 1996]. What is clear is that the amount of road-related mass wasting can be controlled in great degree by means including, but not limited to, helicopter logging, road design, and route selection. Because the amount of sediment from roads by mass wasting depends largely on effort and cost, it is not appropriate to include it in a general analysis. The particulars of the location and road design can be taken into account for specific problems. As stated in our paper [*Istanbuluoglu et al.*, 2004, p. 17], “Therefore our study should be considered as a simple thought experiment as an initial step to more detailed modeling studies.”

[5] *Rhodes* [2005] primarily cites literature relative to the effects of roads on stream peak flows and drainage density. Our model only estimated sediment yield from hillslopes

¹Rocky Mountain Research Station, U.S. Forest Service, Boise, Idaho, USA.

²Civil and Environmental Engineering Department, Utah State University, Logan, Utah, USA.

³Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts, USA.

and hollows and did not consider stream transport. The paper does not disclose predictions of drainage density under the managed regime, so the statement that the drainage density is underpredicted is incorrect. Also, the papers that Rhodes [2005] cites present a clear hypothesis via mechanistic descriptions and modeling studies to suggest that roads affect peak flows; however, such observational evidence as exists suggests only a mild effect [Jones and Grant, 1996; Thomas and Megahan, 1998]. Furthermore, there is some question about the complete details of the mechanistic explanation related to topographic effects on interception of subsurface flows [Luce, 2002]. We have, however, attempted to address the spirit of his comments in the paragraphs above.

[6] A related analysis by Elliot and Miller [2002] compares surface erosion from forest operations (thinning, prescribed fire, skidding, roads) over a long period to surface erosion from a given fire event or series of fire events. They predicted that fires are a much greater source of sediment in the long term. Considering that the Water Erosion Prediction Program does not predict mass wasting or gully-related erosion and the fact that they modeled low-gradient roads (4–8%) and hillslopes (maximum slope 50% or 26°), the result is a little surprising. It underscores the lack of sediment contribution from roads but leaves the question begging, What about steeper landscapes and other erosion processes?

3. Fire and Harvesting

[7] Part of our intention in developing the model was to consider the stronger geomorphic agents of mass wasting, specifically, landslides and gullies, in the discussion when considering the balance between harvest and wildfire. While Rhodes [2005] would suggest that we underestimate the effects of harvest, others will undoubtedly take issue with the fact that a clear-cut harvest was applied with no buffering for slope stability, potentially overestimating the effects of harvest. What is important is that a significant component of the complexity, and a large component of the sediment yield, not available in earlier analyses, has been added into the discussion.

[8] Rhodes's [2005] assertion that the model did not consider the fact that management does not exclude fire is correct, and it is likely to cause a bias as well. It is not clear how well fuel treatments will affect occurrence or severity of fires. As of the time the modeling was done, the papers that Rhodes [2005] cites were not available, and the only evidence for fuel treatment effectiveness was anecdotal. We chose to model as though harvesting and management access for fire fighting would so substantially reduce fire occurrence and severity that it could be ignored on the 300 year modeling time frame we used. It is not entirely clear how the model might respond to a parameterization to include fire with some reduced likelihood, other than to see some increase in sediment yield in the short term. In our paper [Istanbulluoglu et al., 2004, paragraph 74], we noted some caveats about length of simulation relative to the occurrence of fires, and underestimating the relative sediment yields from harvest treatments, fire with lesser likelihood would be even more poorly represented. Conceptually, we intended to compare a managed system with all the

benefits of suppression to one with no management and no suppression.

4. Water Repellency

[9] We disagree with Rhodes's [2005] characterization of the water repellency as being overestimated. Detailed measurements of fractional water repellent area have now been made for four recent fires in the Idaho Batholith. These consistently show a spatial distribution of 90–95% water-repellent soils for severely burned sites, and a lower bound of around 40% fractional water-repellent area was found on two of the fires that experienced a moderate severity burn [U.S. Department of Agriculture Forest Service, 2003]. "Naturally" occurring water repellency in unburned areas had about 20% coverage on two of the fires. Measurements in the surrounding area are probably the best source of information for a modeling study. Doerr and Moody [2004] noted the lack of published measurements of the spatial pattern and extent of water repellency, so there are no real alternatives for an estimate. The model does not depict the burned area as completely impervious but as partially pervious, using equations (30)–(32) [Istanbulluoglu et al., 2004] to estimate the initial fire-related alteration to fractional water repellent area and its evolution over time. The grain of water repellency is very small (on the order of millimeters), and we treat the fractional area coverage as a point process and effectively modify the infiltration capacity of the soil by the fractional water repellency for higher rainfall rates. Runoff may be somewhat overestimated for lesser precipitation events, but those are not responsible for the bulk of the soil movement. Note that some methods of measuring infiltration rates will not be affected by water repellency, particularly those with any driving head applied, which are typically applied at very small spatial scales. Other methods of measuring infiltration rates will integrate over repellent and nonrepellent areas to obtain the averages cited by Wondzell and King [2003]. At 90% water repellency, our effective infiltration capacity is 40 mm/hr, which compares favorably with the range Rhodes [2005] provides.

5. Conclusion

[10] To conclude the direct response to the comments by Rhodes [2005], Rhodes [2005] brings up some limitations of the comparison that was done; however, we present evidence that the consequences are not as great as he estimates and do not represent "major biases." We excluded roads from the analysis because we wanted a simple model independent of the specific details of road standards and because it is becoming clear that although roads contribute fine sediment that results in muddy waters, their contribution to total long-term sediment yield is relatively minor. Including roads in the model would detract from the focus of the paper on mass wasting processes on burned or harvested sites. We did not consider the effects of fire conditioned on fuel treatment in an area because there was no clear data on the degree of effectiveness, or lack thereof, from treatments. We are glad to have the opportunity to provide additional information in support of our water repellency estimates. As is common in modeling studies, there are opportunities for more detailed modeling

and analysis of sensitivity to the assumptions and opportunities for measurements to better estimate process rates. Hopefully, the reader can see how to use the information from the article as one more piece of evidence in a complex analysis comparing relative benefits and costs of fuel treatments and wildfires to aquatic ecosystems.

[11] Although Rhodes's [2005] question is about sediment yield, it is not without the context of the broader question of whether large fires or the fuels management and suppression intended to mitigate those fires represents a greater long-term threat to aquatic species [Rieman et al., 2003a; Beschta et al., 2004]. Within this context, we believe that Rhodes's [2005] focus on sediment yield from roads misses potentially more important spatial and temporal scales of analysis for aquatic ecosystems. Although road erosion does not add up to much over time, a chronic, rather than pulsed, supply may have a notable effect on aquatic ecosystems at several trophic levels. Likewise, ubiquitous road-derived sediment in streams does not allow for spatial refuge from temporally chronic effects in some basins. Thus the spatial and temporal distribution of fine sediment inputs from roads may be a better measure of their impact than the total mass. The minor amount of sediment from roads relative to the apparent long-term yields for basins like the ones we modeled also suggests that catastrophic events may tell a more important story. The ecological literature, for example, suggests that isolation and fragmentation of aquatic habitats together with catastrophic disturbance may strongly influence the potential for local extinction for species like salmonid fishes [Rieman and Clayton, 1997; Dunham et al., 2003; Rieman et al., 2003b]. Our work shows that management may fundamentally alter the temporal pattern and magnitude of mass erosional events, while others have found that road crossings are a major cause of fragmentation in aquatic habitats [Lee et al., 1997]. The combination could lead to fundamentally different patterns of species endangerment than we could anticipate with a simple analysis of sediment produced from roads.

[12] While traditional sediment yield analyses, long the standard of effects analyses in silvicultural systems, can be helpful in decision making about fire versus management, relying solely on such analyses to decide between alternative actions may miss the larger issues [Luce et al., 2001]. Our paper [Istanbulluoglu et al., 2004] has provided some geomorphic insight into the fact that in steep basins, there is a long-term limitation in sediment yield by soil production, giving us sediment yields on a similar order of magnitude from wildfire and harvest in the long term.

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E. Istanbulluoglu, Department of Civil and Environmental Engineering, Massachusetts Institute of Technology, MIT Room 48-114, Cambridge, MA 02139, USA. (erkan@mit.edu)

C. H. Luce, Rocky Mountain Research Station, U.S. Forest Service, 316 East Myrtle Street, Boise, ID 83702, USA. (cluce@fs.fed.us)

R. T. Pack, and D. G. Tarboton, Civil and Environmental Engineering Department, Utah State University, 8200 Old Main Hill, Logan, UT 84322-4110, USA. (rtpack@cc.usu.edu; dtarb@cc.usu.edu)